Passive coherent combining of two high-brightness tapered laser diodes in a Michelson external cavity

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High-brightness direct diode laser systems are becoming prominent in the laser industry, thanks to their high wall-plug efficiency. As the brightness of single emitters is physically limited, multiple laser diodes need to be combined in order to scale up their performance. Among the different combining techniques, coherent beam combining (CBC) specifically results in a single high-power laser beam with excellent spectral and spatial properties[1]. But it can only be achieved in an arrangement that forces the required phase relation between the emitters. We propose a newCBC architecture for the passive phase-locking of a diode laser array that is designed to ensure a stable high-power operation and a high electrical-to-optical efficiency. It uses a common laser external cavity on the back side of the emitters for phase locking, while coherent beam superposition of the phase-locked beams is realized on the front side [3]. As a consequence, a strong optical feedback is achieved on the back facet to maintain the phase-locked operation at high currents, and losses are minimized on the useful output on the front side.

For this experiment, we used two tapered laser devices emitting around λ = 976 nm[4].The lasers were mounted p-side up on C-Mount to allow access to both facets. They contain a 2 mm long ridge section, and a 4 mm long tapered section (6° taper angle). The two sections are separately driven by currents I_R and I_T, respectively. After external stabilization, the extracted optical power reaches 4 W at I_R = 400 mA and I_T = 6 A, corresponding to an electrical-to-optical (E-O) efficiency of 26%. The beam is diffraction-limited along the fast axis; along the slow axis the beam quality factor is $M^2_{4\sigma} \approx$ 2.5 at I_T = 6 A.The external cavity is based on a Michelson interferometer on the rear-side: the two laser beams are combined on a 50/50 beamsplitter (BS), and a diffraction grating at Littrow incidence on one arm closes the external cavity[3]. Since both lasers share the same external cavity, they undergo minimum losses if the two laser beams are in phase at the BS – resulting in constructive interference in the direction of the diffraction grating, and destructive interference on the other BS arm. This external cavity forces phase-locked operation of the two tapered lasers. On their front facet, a 50/50 BS is used as a combiner to perform coherent superposition of the beams.

The maximum combined optical power is 6.5 W at I_T = 6 A and I_R = 400 mA, corresponding to a combining efficiency η' = 82%; the E-O efficiency $\eta_{E\text{-}O}$ is thus ≥ 21%. We observe that the external cavity on the rear side acts as a lateral mode filter: the beam quality is improved to $M^2_{4\sigma} \leq 1.3$ when the two emitters are phase-locked. And since the combining stage on the front facets operates as a second spatial filter rejecting high-order lateral modes, the beam quality of the combined beam is further enhanced to $M^2_{4\sigma} \leq 1.2$. Finally with an actual spatial filtering stage on the output beam, weare able to select only the central diffraction-limited lobe of each beam. The measured combining efficiency increases to 92%, corresponding to a combined power of 5.9 W in the filtered beam and a spatial brightness above 500 $MW/cm^2/sr$.

The short-term stability of the phase-locking is guaranteed by the common cavity, as the lasing frequency passively self-adapts to maintain a zero-phase difference between the two beams on the rear BS. The long-term stability of the CBC cavity is ensured with a semi-active feedback loop implemented on the ridge-section currents of both devicesthat maintains the combined power at its maximum.

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